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Controlling Unmanned Vehicles: the Human Factors Solution

Jan B.F. van Erp
TNO Human Factors Research Institute
Kampweg 5
NL - 3769 DE, Soesterberg
The Netherlands
vanerp@tm.tno.nl

Abstract

Recent developments and experiences have proven the usefulness and potential of Unmanned Vehicles (UVs). Emerging technologies enable new missions, broadening the applicability of UVs from simple remote spies towards unmanned combat vehicles carrying lethal weapons. However, despite the emerging technology, unmanned does not implicate that there is no operator involved. Humans still excel in certain tasks, e.g. tasks requiring high flexibility or tasks that involve pattern perception, and decision making.

An important subsystem in which the technology driven aspects and the human factors driven aspects of UVs meet is in the data–link between the remote vehicle and the operator. The human factors engineer wants to optimize operator performance, which may require a data–link with an extremely large capacity, while other design criteria typically limit the bandwidth (e.g. to lower costs, or because no more bandwidth is available in certain situations). This field of tension is the subject of the present paper.

The paper describes two human factors approaches that may help to resolve this field of tension. The first approach is to reduce data–link requirements (without affecting operator performance) by presenting task–critical information only. Omitting information that is not needed by the operator to perform the task frees capacity. The second approach is to optimize performance by developing advanced interface designs which present task–critical information without additional claims on the data–link. An example will be given of both approaches.

1 Introduction

Nowadays, Unmanned Vehicles (UVs) come in different kinds and forms (see Figures 1 and 2). The last decade, UVs have shown that they have the potential to play an increasingly important role on the future battlefields. For example, in the next decades, an increasing transition from air based cockpits to ground based cockpits for use with man-in-the-loop UAVs is foreseen.

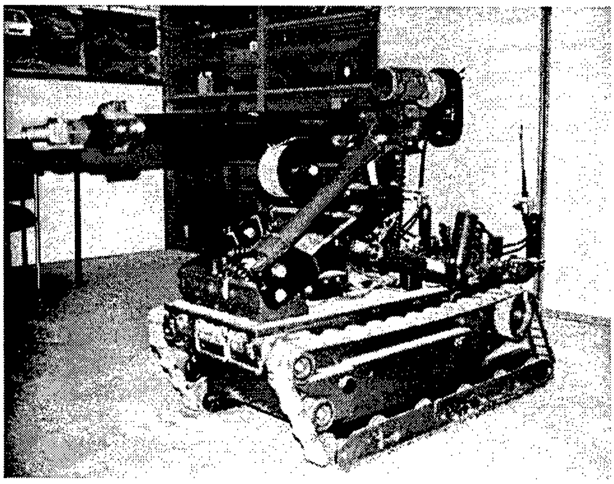

Figure 1. Example of an Unmanned Ground Vehicle for ordnance disposal as in use by the Royal Netherlands Airforce.

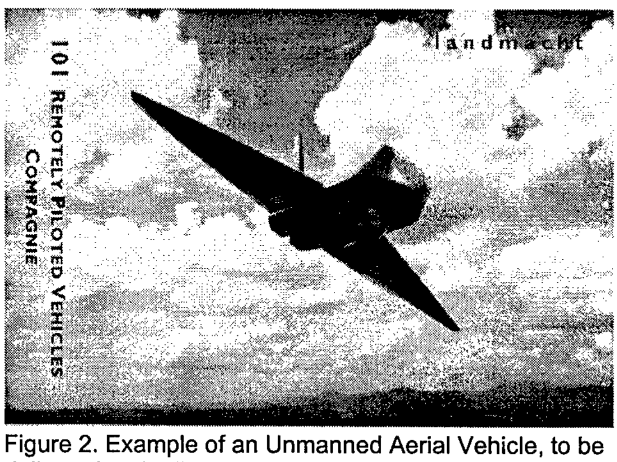

Figure 2. Example of an Unmanned Aerial Vehicle, to be delivered to the Royal Netherlands Army during 1999.

The primary advantage of UVs is the reduced risk of casualties and losses of personnel. In the light of the changing role of NATO with more emphasis on humanitarian and peace keeping operations, UVs can also help preventing the loss of the public support. Furthermore, UVs are better suited for dull or dangerous tasks (e.g. long–endurance missions and

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missions in NBC contaminated areas), and UVs may be much cheaper than their inhabited counterparts.

Emerging technologies enable new missions, broadening the applicability of UVs from simple remote spies towards unmanned combat vehicles carrying lethal weapons. However, despite the emerging technology, unmanned does not implicate that there is no operator involved. Humans still excel in certain tasks, e.g. tasks requiring high flexibility or tasks that involve pattern perception, and decision making, and humans are certainly required in the case of weapon delivery. Typical tasks that are allocated to the human operator include: mission planning, interpreting images from the remote location, decision making and weapon delivery. This means that system performance both depends on technological developments and on human factors considerations. More strongly, it may be stated that the human–in–the–loop is critical for mission completion.

System integration

Human factors knowledge may be required for different aspects of the system design. Questions and aspects that involve human factors considerations include: task–analysis (which tasks are allocated to the machine, and which to the operator), the number of vehicles one operator can control, interface design, workload, team performance, and selection and training of personnel. An important subsystem in which the human factors aspects and hard and software technology converge is in the data–link between the remote vehicle and the operator. At the same time, this subsystem embodies the field of tension between human factors requirements and other design considerations. For example, dynamic tasks like steering and orientation tasks, typically require a steady stream of images. Optimizing operator performance for these kind of tasks may result in a data–link with an extremely large capacity. On the other hand, other design criteria force to limit the bandwidth capacity (e.g. to lower costs, or because no more bandwidth is available in certain situations). This field of tension is the subject of the present paper.

The paper describes two human factors approaches that may help to resolve this field of tension. The first approach is to reduce data–link requirements by presenting task–critical information only, and therefore omit information that is not needed by the operator to perform the task, but unnecessarily uses data–link capacity. The second approach is to optimize performance by developing advanced interface designs which present task–critical information without additional claims on the data–link. An example will be given of both approaches. In driving unmanned ground vehicles via a camera–monitor system, careful consideration of image parameter values can reduce the required data–link capacity considerably to normal video images. In applying advanced interface designs in controlling the on–board camera of a UAV, operator performance can be improved without enlarging the data–link capacity. Both methods may help to reduce the data–link capacity without compromising on operator (and system) performance.

2 Effects of the tele–operation environment on operator performance

By employing a UV, one of the goals is to combine the remoteness of the environment with some form of human intelligence (otherwise one could for example employ an unguided missile). The ultimate goal is that the operator can act and perform as if he or she was really present at the remote location (or even better), e.g. the camera operator of a UAV must be able to search and identify objects as if he or she was actually flying above the terrain of interest. However, one of the larger obstacles on this road is the sensory deprivation inherent to a tele–operation situation. The operator is not present in the remote vehicle and has no direct sensory contact with the remote environment. Ergo, sensory information must be mediated with the help of on–board sensors. The inherent information degradation may negatively affect operator performance.

Below, some examples are given of degraded or lacking information and the possible consequences. A more detailed picture regarding remote camera control is sketched in Section 4.1.

1. The most important source of information from the remote environment is usually the image of an on–board camera. It is not common to provide other forms of sensory information, such as forces in controls when turning a curve, auditory information on forward speed, and proprioceptive information on vehicle swaying. This (redundant) information may enhance performance on tasks like speed estimation, and

controlling lateral acceleration.
2. Furthermore, the visual information that is provided will be of a degraded quantity (e.g. reduced spatial resolution, field size, and colour) compared to direct viewing. This will directly affect performance on detection and identification tasks, and may also lead to disorientation of the operator.
3. Data–link restrictions will further degrade the available visual information. This may, amongst other things, result in low update rates of the images. When the refresh rate becomes lower, and the presentation becomes snap–shot like, performance on tracking, steering, and orientation tasks will be directly affected.
4. Finally, in the tele–operation environment, the control devices may provide less information. An example is joystick camera control which will omit the use of the high quality information from neck and eye muscles on viewing direction which are available when an observer is situated inside a helicopter and uses a pair of binoculars.

Tasks that are especially affected by degraded sensory information are orientation and manual control tasks. Although getting the operator out of the loop (e.g. employ automated line scanning, or target tracking) may seem to solve this problem, it does not automatically improve system performance. First, by introducing automation, the role and tasks allocated to the operator change, and this is often not a change for the better, because:
1. The operator ends up with tasks that can not be automated (which doesn't mean that the operator is good at it),
2. The operator's role changes from manual to supervisory control, which will induce new kinds of failures (failure to monitor, vigilance decrement, over reliance on standard values, automation–induced complacency, increased latency in detecting problems etc.),
3. Operators may be frustrated by having to watch an automate performing a task, while they are not able to intervene (e.g. operators will certainly want to intervene when a remote camera scans the environment, and the operator detects something of interest).

Second, there are situations in which manual control modes are favoured over automation or a fully autonomous vehicle. For example:
1. Manual camera control enables optimal use of human expertise concerning information gathering tasks (e.g. to recognise and interpret details of weapon systems, and to use knowledge of common lay–outs of convoys).
2. The technology for tasks as automatic target tracking and recognition may be insufficient. It is believed that target motion may not be sufficiently predictable to warrant human tracking (Eisen & Passenier, 1991a,b). Detection and identification of unwilling objects in video–images still can't be reliably automated, although operator cueing might be possible.
3. Even in automated processes, it may be expected that operator intervention will occur, e.g. in order to influence the target–search pattern (Moody &Thompson, 1989), to avoid boredom, or to maintain situational awareness (Tirre, 1998).
4. The technology to automatically drive a ground vehicle in unknown (off-the-road) terrain is insufficient for driving with high speed. The human operator excels in obstacle avoidance and path finding.
5. Both takeoff and landing are sometimes accomplished manually with a camera mounted in the vehicle's nose (e.g. Predator UAV).

3 Reducing data–link capacity by omitting non–critical information

An important contribution of the human factors engineer is determining task–critical information. Figure 3 shows the rationale behind this approach. The graph shows typical results found in human factors research. Lowering a specific system parameter (e.g. the update rate, colour depth, or spatial resolution of the images of the remote environment), will result in a slow decrease of operator performance until a specific level (marked by the arrow in the graph). When the level of the parameter is lowered below this level, performance will suddenly drop. In the example depicted in the graph, the system parameter (and therewith the data–link capacity) may be halved, resulting in only a small performance decline.

For all kinds of tasks and environments, this procedure may result in data–link reductions without performance loss. An example is given for the manual control of an uninhabited ground vehicle (UGV), in which the driver steers and navigates through the remote environment on mediated images from an on–board camera. The next Section gives an overview of the most important image parameters,

and their optimal value in the field of tension between operator performance and data–link capacity.

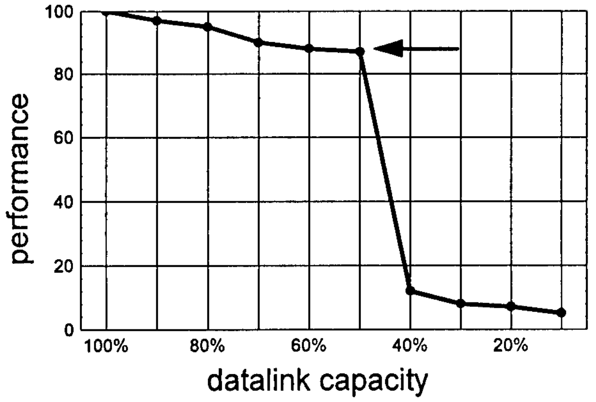

Figure 3. Illustration of omitting non–critical information. Performance decline is not linearly related to data–link capacity.

3.1 task–critical information in UGV control

To fully employ the human skill to safely drive a vehicle with high speed through unknown terrain, manual control may be preferred over fully autonomous. However, this operator task is far more difficult than normal driving. The perceptual input for the operator is usually restricted to mediated images from an on–board camera, no force, auditive, or proprioceptive information on vehicle behaviour and speed is available. Furthermore, the visual information that is available is of degraded quantity compared to normal driving (e.g. reduced spatial resolution).

The required quality of the mediated information on one hand and the need to restrict the data–link capacity on the other, ask for a careful consideration of image parameters. The goal must be to come to operational requirements for the most economic man–machine–interface without hampering operator performance and vehicle usability.

Based on studies on driving behaviour, literature reviews, and pilot studies, the critical image parameters can be identified. These parameters were studied in different research projects and experiments at TNO. The overview and recommendations given below are based on field and simulator studies.

The following image parameters can be critical in vehicle control:

- **Field size**: the field size is directly related to the needed data–link capacity (when the relative resolution is constant). Normally speaking, the field size of the images will be considerable smaller than the field size of normal drivers (more than 140° horizontal field of view). If the field size is lowered, the operator will experience the remote world as looking through a tube. Smaller field sizes will hamper the use of peripheral vision, and may hamper the perception of speed, orientation capability, and other tasks. Research has shown that a minimum field size of 50° diagonal is required, while 100° is preferable (Van Erp & Padmos, 1998). It is recommended to consider enlarging the horizontal field of view (FOV) at the expense of the vertical FOV for driving on flat terrain.

- **Magnification factor**: employing a magnification factor smaller than 1.0 may be advantageous to enlarge the field of view. However, these magnification factors will result in biases in the perception of speed and distances, and in less object motion on the display. The latter may degrade performance, e.g. enlarge the course instability. Swaying of the vehicle will result in smaller object motion on the display, and is therefore harder to control. Moreover, the operator has no vestibular information to detect vehicle swaying! (Van Erp & Padmos, 1996).

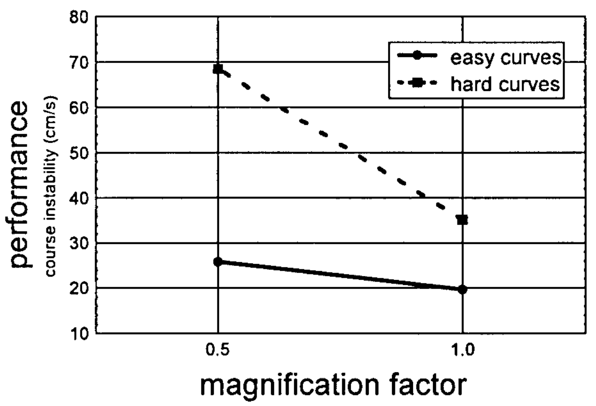

Figure 4. Example of performance degradation with magnification factors smaller than 1.0 which is especially present in critical tasks.

Figure 4 shows a typical example of the effect of magnification factor on the course instability in taking curves (Van Erp, 1995). Especially in critical tasks, magnification will degrade performance (in this example, the course instability doubles with a magnification factor of 0.5). Concluding: magnification factors less than 1.0 must be avoided,

they are disastrous for driving performance, especially because the operator has no mechanical motion information.

- **Black and white vs. colour** images: for driving on paved terrain, black and white images are sufficient. However for driving in rough terrain, the estimation of ditches and other terrain characteristics is essential for good driving. Experienced drivers report that they partly rely on colour information (Van Erp, Van den Dobbelsteen & Padmos, 1998). The importance of this cue increases when there are no stereoscopic depth cues, and when image quality becomes less.

- **Update rate**: update rate is a very important parameter. Lowering the image update rate is a very easy way to reduce the data–link capacity. However, low update rates will hamper the perception of motion, speed, and heading, and may degrade the situation awareness of the operator. Especially in dynamic tasks, operator performance will be affected by lowering the update rate. Figures 5 and 6 give examples of the effect of update rate on driving performance in dynamic tasks. Critical update rates are 10 and 5 Hz for turning curves and a lane–change task respectively. In non–dynamic tasks (e.g. the estimation of distance), update rates may be lower. Typical experimental results show that the minimum required update rate is strongly task dependent, and ranges between 3 Hz to 10 Hz (Van Erp, 1996).

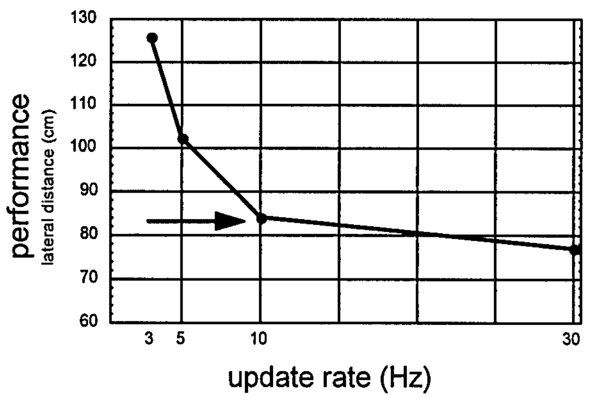

Figure 5. Effect of lowering the update rate on operator performance in turning curves. Critical update rate for this task is 10 Hz.

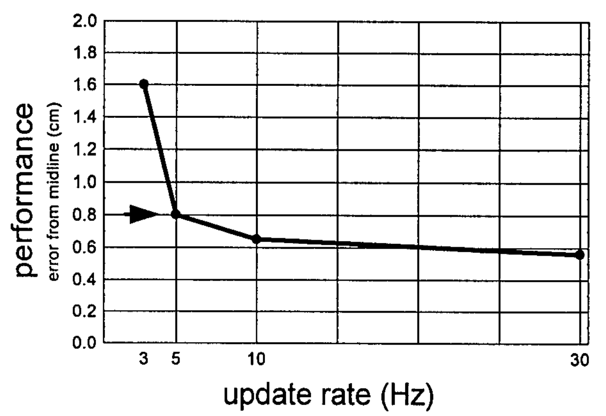

Figure 6. Effect of lowering the update rate on operator performance in a lane–change task. Critical update rate for this task is 5 Hz.

- **Spatial resolution**: the spatial resolution of an indirect viewing system will always be lower than that of the human eye (e.g. the resolving power of a 50°diagonal PAL image is about 0.5 arcmin^{-1}, in direct view, an acuity of 2 arcmin^{-1} is not uncommon, Van Erp & Padmos, 1994). Spatial resolution is probably very important in driving through rough terrain, in which the perception of terrain characteristics is very important. However, for driving on flat, paved terrain, the spatial resolution may be highly reduced. For example Van Erp (1996) found no performance degradation for turning curves with a spatial resolution as low as 64×60 pix. for a 80°×60° H×V field size. For driving in terrain, the resolution must be at least twenty times larger.

- **Monoscopic vs. stereoscopic** viewing: for driving on flat or paved terrain, monoscopic viewing is sufficient. However, although stereoscopic depth cues are only profitable up till about 10 m., taking ditches and obstacles are tasks in which the absence of stereo vision will hamper performance, especially when the visual information is already degraded. This is illustrated in Figure 7, in which chauffeurs drove an armoured vehicle over a course with larger and smaller ditches. Different visual conditions were employed: direct view, in which the driver was only wearing field size restricting goggles, and indirect viewing with the same field size. In both visual conditions, the drivers performed the task with mono and stereo vision. The figure shows that the positive effect is apparent under indirect (degraded) visual conditions (Van Erp & Van Winsum, 1999).

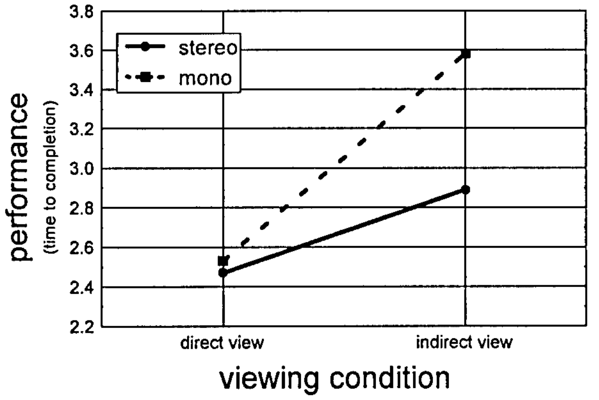

Figure 7. Effect of stereoscopic depth cues on driving performance in rough terrain. The positive effect of stereoscopic cues increases under degraded visual conditions.

- **Fixed vs. variable viewing direction**: a variable viewing direction (e.g. implemented with a pan and tilt camera, or by using different cameras with a fixed viewing direction), gives the operator a large field of regard with a small instantaneous field of view. However, a disadvantage of a variable viewing direction is that operators have difficulties in determining the viewing direction of the camera, and the heading direction of the vehicle. Different remedies can be introduced to reduce this disorientation, of which the strongest is to provide adequate vehicle references, that indicate the viewing direction compared to the vehicle. An other possibility is to make the viewing direction head–slaved, which gives the operator intuitive information on viewing direction (Van Erp & Kappé, 1997). This latter method, however, is very susceptible to factors as time delays in the data–link, and overshoot of the platform.

- **Placement and aiming** of the camera: make sure that the camera image contains a part of the vehicle. The availability of vehicle references enhances both driving performance and situational awareness (Padmos & Van Erp, 1996).

3.2 Conclusions

Given a specific data–link capacity, operator performance can be optimized by giving the operator the possibility to:

1. manually tune the update rate and spatial resolution required to perform the task,
2. reduce the vertical field size for driving on flat terrain,
3. choose for black and white images and monoscopic viewing for driving on paved terrain.

Further optimization may be accomplished by introducing head–slaved camera control with a limited instantaneous FOV. The above example shows that system performance may be enlarged by carefully choosing what information the restricted data–link is used for.

4 Reducing data–link capacity by applying advanced interface design techniques

To optimally employ the human expertise in remote camera control tasks such as target detection and identification, battle damage assessment, and the gathering of intelligence information, image analysts must preferably be able to manually control the on–board camera. This section discusses the second approach to enlarge system performance without additional claims on the data–link capacity: employing advanced interface designs. The possibilities of this approach will be discussed for an other task environment, namely remote camera control.

Remote camera control is much more difficult than looking to the outside world with a pair of binoculars. The first paragraphs will introduce the possible problems in remote camera control and the possible consequences for the operator. In the following sections, four examples are given of advanced interface designs that reduce the consequences of specific interface characteristics that are of primary concern in the design of UAV systems, including: field size, zoom factor, update rate, transmission delays, and lack of proprioceptive information on viewing direction.

4.1 Possible problems in remote camera control

In remote camera control, the operator views the world through mediated camera images. Amongst other things, data–link restrictions will engender camera images that are of less quality compared to images perceived directly by the human eye. Furthermore, the following shortcomings are typical in remote camera control (Van Erp & Van Breda, 1999):

- There is no proprioceptive feedback provided in the controls. In manual control mode, for instance in a situation that the camera is controlled by means of a joystick, the control will not give feedback on camera behaviour

whatsoever;

- There is no vestibular feedback on vehicle attitude. Because the operator is not seated in the vehicle, vestibular information on vehicle behaviour (e.g. rotations) is missing. This means that the operator has no relevant information on changes in flying direction;
- There is no proprioceptive feedback on viewing direction. When the observer is situated on–board a vehicle, proprioceptive information of muscles in neck and eyes provides exact information on the viewing direction. In a tele–operation setting, where visual information is presented on a fixed monitor, this information is missing;
- There is no direct feedback on control input. When the operator produces an input signal, the result of this action will not directly be available. Delayed feedback may seriously degrade manual control performance, ultimately leading to a go–and–wait strategy (bang–bang control, overshoot) when time delays are considerable;
- Limited spatial resolution of the camera images. This is a crucial parameter in all camera control tasks (predominantly in detection and identification tasks). Enlarging the limited resolution per degree of visual angle by reducing the field size will also hamper operator performance (see below).
- A limited geometrical field of view (GFOV). A small GFOV may have several consequences. Firstly, the size of the GFOV is directly related to the required camera motion to scan a given area. Secondly, smaller field sizes will hamper the spatial integration of objects in the remote environment, will inhibit building up situational awareness, may lead to operator disorientation (especially since the sensor slewing will be relatively quickly (Carver, 1987)), and complicates the task of keeping track which areas are already searched (Carver, 1988), and where threat areas lie. Thirdly, if the operator chooses to manually slew the sensor, the workload is expected to increase as the GFOV decreases. And finally, in tracking tasks, the motion of a target relatively to the monitor screen will increase, which will decrease tracking performance (Poulton, 1974).
- A zoomed–in camera image. The limited field size, the limited resolution, and the minimum stand–off distance combined will force the operator to zoom–in on targets. Because a zoomed–in camera image disturbs the normal relation between camera rotation and translational flow in the camera image, this may be an important factor in operator disorientation. When based on the translational flow, the camera rotation will be overestimated.
- Limited update rate of the image. Lower update rates of the camera image will mainly affect dynamic tasks. Update rates below 10 Hz will decay the perception of the motion of the target, and of the camera and the platform. Very low update rates will lead to a snapshot like presentation of images, without any perceptual information on motion.

Concluding, sensory information on the remote environment may be lacking, or may be of lower quality as compared to the situation in which the operator is located inside the vehicle. The possible consequences on operator performance are described in the next Section.

4.2 Possible consequences on operator performance

Prioritizing the above list, the important bottlenecks for manual camera control are the quality of the visual information from the remote environment, and the lacking of (proprioceptive) cues on camera viewing direction. Significant consequences for the operator are poor tracking performance (resulting in large tracking errors, and losing the target), difficulties in assessing camera, platform, and target motions, confusion on the flying direction of the platform, confusion on the viewing direction of the camera, disorientation, and degraded situational awareness.

4.3 Reducing low update rate consequences

The focus of this example is on improving camera control under low update rate conditions. The underlying study (Van Erp, Korteling & Kappé, 1995) included two experiments in which the operator of a UAV camera is supported by synthetic visual motion information. On the basis of knowledge about the present position and orientation of UAV and camera, system characteristics, and control inputs, an artificial grid of perpendicular lines can be presented over the camera image (a graphical overlay) that specifies the various components of UAV and camera motion (see Figure 8). This means

that when the camera image is refreshed with lower update frequencies, the perpendicular lines move relative to a static camera image.

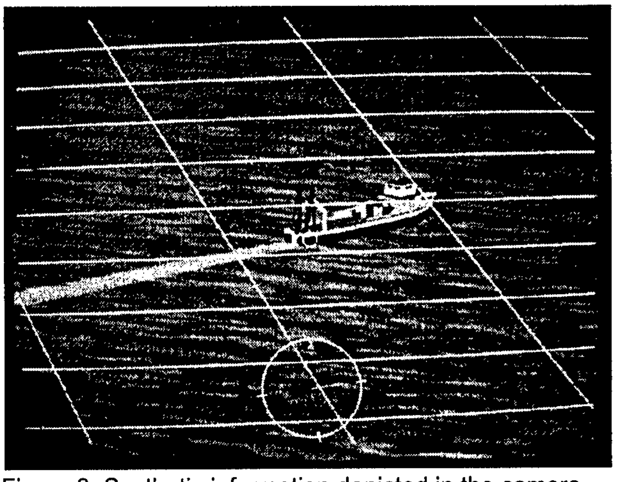

Figure 8. Synthetic information depicted in the camera image provide high quality motion information despite the update rate of the camera image.

It was expected that this (fast updated) synthetic image augmentation would help the operator in perceiving movements of UAV and camera, and therefore that it would improve the tracking and orientation performance of the operator. This hypothesis was tested in two experiments. In the first experiment subjects had to track a moving target ship from a moving platform, which meant compensating for translations and rotations of both the ship and the UAV. The results showed a significant positive effect of synthetic image augmentation (up till a factor 2). This effect became stronger in the conditions with low update frequencies (see Figure 9).

The second experiment involved a situational awareness task. After imposed translations and rotations of the UAV and camera during 15 s, the subjects' task was to point the camera at the position of a previously depicted target ship. This experiment too showed a significant positive effect of synthetic image augmentation on performance, which increased in the conditions with lower update frequency. This indicated that mutual positional relations were better memorized in the presence of the graphical overlay and, thus, that relative situational awareness was improved.

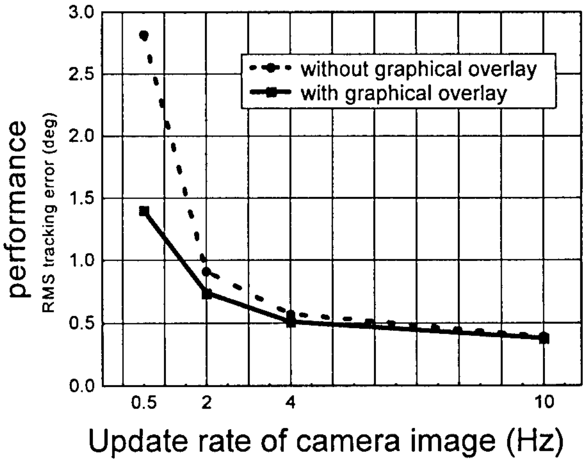

Figure 9. The positive effect of the graphical overlay increases with lower update rates.

4.4 reducing degradation of SA caused by zoomed–in images

The second example concerns an 3D graphical interface to improve situational awareness. A computer generated world (CGW) over and around the camera image was developed (see Figure 10), in order to counteract the disorientation caused by zoomed–in camera images (a comparable situation is present when people lower their pair of binoculars to re–orientate themselves).

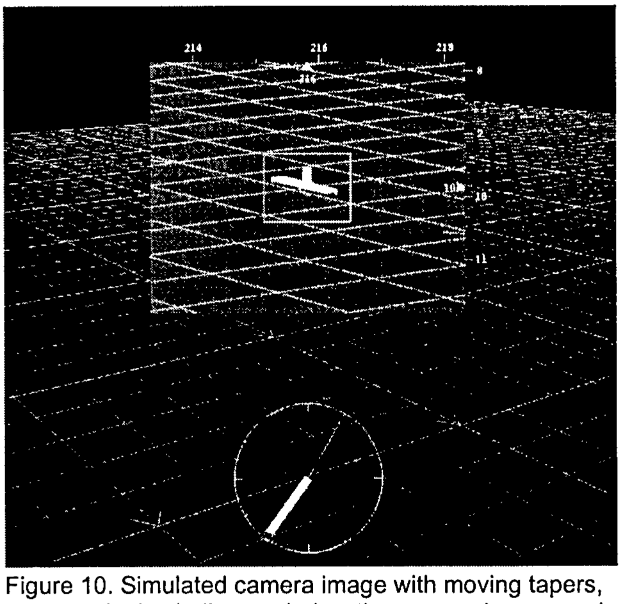

Figure 10. Simulated camera image with moving tapers, the quantitative indicators below the camera image, and the perceptually correct computer generated grid depicted over and around the camera image.

This CGW was perceptually correct, in that it

resembled the view on the world from the UAV as if the operator was on-board (Van Erp, Kappé & Korteling, 1996). The results from the experiment substantiated the effectiveness of the CGW in improving the operators search performance: the search time and the total camera motions were significantly reduced when the CGW was presented (see Figure 11). Thus the CGW can counterpart the negative effects of a zoomed–in camera image and subsequently improves situational awareness. Supporting the operator by means of quantitative indicators, depicting camera heading and pitch, did not show any significant improvements in performance.

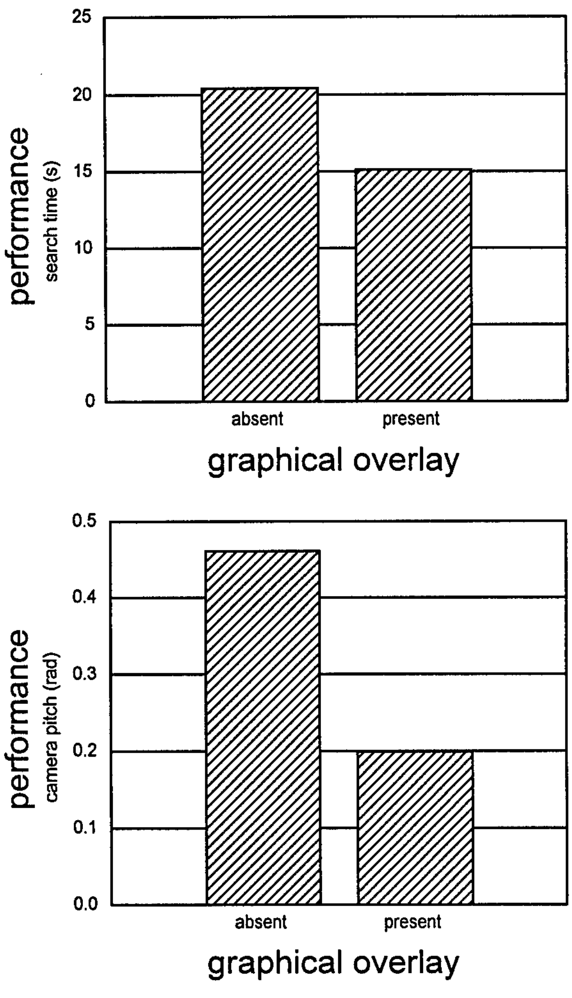

Figure 11. The positive effect of the graphical overlay is present on different objective performance measures.

The information provided by the CGW is fundamentally different from the information provided by the indicators. Gibson (1950) assumes that the information such as provided by the CGW may be picked up directly by the visual system, without demanding substantial visual attention. Therefore, the term ecological display was introduced for this type of displays. The more traditional (non ecological) methods of operator support all require the operator to use some kind of cognitive strategy to infer the UAV attitude from the presented (abstract) information.

4.5 Path prediction to counteract time delays

Another factor that may seriously degrade operator performance in UAV control is a time delay between control inputs and subsequent feedback about these inputs to the operator. Figure 12 gives an example of a radar display that includes a prediction of the camera footprint motion. The same technique may be used for electronic maps.

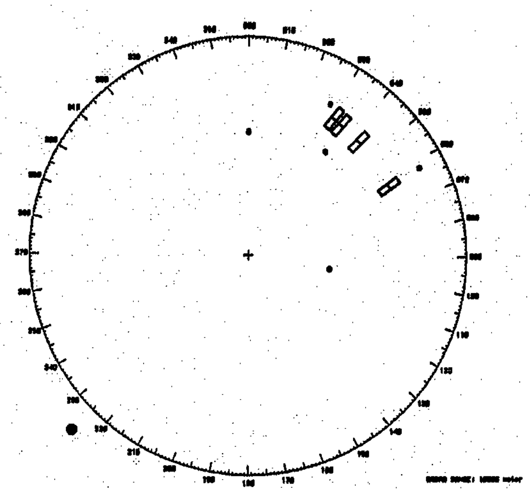

Figure 12. Simulated radar image with footprint prediction. The footprint prediction moves in real time, and indicates the location of the images to come.

Results of search task experiments showed that operator performance decreased when the update frequency is below 2 Hz, or when the time delay is larger than 2 s (Van Erp & Kappé, 1998). The presentation of a predictor led to better performance (see Figure 13), although it could not fully prevent performance degradation at 0.5 Hz update frequency.

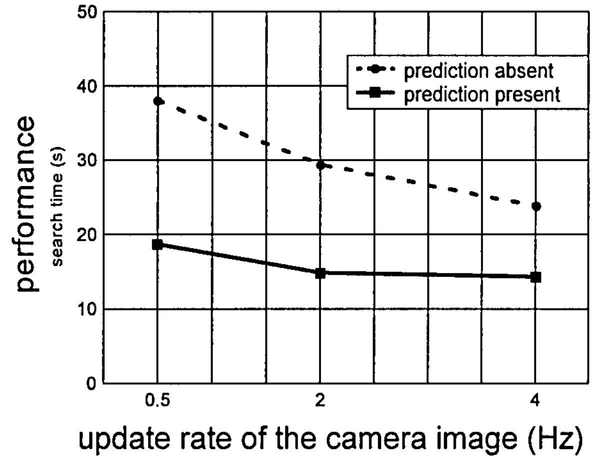

Figure 13. Footprint prediction has a positive effect on operator performance, and makes performance less dependent on update rate.

4.6 Head–coupled camera control

Head–coupled camera control may be a very intuitive way to control the remote camera. Enabling the operator to use high quality (proprioceptive) information on (changes in) viewing direction by introducing a head slaved camera system with a head slaved display (Head Mounted Display or HMD) may improve SA, compared to using a joystick and a fixed monitor. In addition, slaving the camera to the operator's head may benefit performance by reducing cognitive processing; changes in viewing direction do not need to be translated into motor commands for the hand. However, head slaved systems have drawbacks as well, e.g. the weight of the helmet changes eye–head co-ordination may be uncomfortable, and the limited field of view requires the development of different scanning strategies. Furthermore, due to the limited data–link between the remote site and the operator, transmission delays, and the use of enlarged geometric fields of view (zoomed–in cameras), loss of visual stability occurs during camera rotations which may impede adequate mapping of spatial information (the viewing direction of the operator and that of the camera may differ: objects are not located where they are depicted). These drawbacks may counteract the positive effects of head slaved camera control.

Experimental results show that head slaved camera control increases search speed but also enlarges the search path as compared to manual (joystick) control. Furthermore, the results also confirm the increased susceptibility to mismatches between visual information and proprioceptive information due to time delays or zooming (Van Erp & Van den Dobbelsteen, 1998a, 1998b).

Figure 14. Experimental setting in which the operator controls the simulated camera by means of a head–coupled sensor.

4.7 Concluding remarks

The results of the examples show that innovative interface design can significantly improve operator performance without removing the human operator from the control loop or enlarging the data–link requirements. It should be noted that these experiments should be viewed as examples of the contribution of human factors to the design of interfaces. They only showed a limited set of possibilities to enhance operator performance. For instance, other types of displays (e.g., tactile or 3D auditory displays) or emphasis on operator training methods may also be employed in order to support the operator in (multiple) UAV control methods.

5 Conclusions

The paper described two human factors approaches to reduce the field of tension between operator performance and data–link capacity. The first approach is based upon developing the most economical man–machine interface by presenting task–critical information only, and omit information that is of less or no use to the operator. The idea is that omitting this information reduces the data–link requirements, without hampering operator performance. This approach was illustrated with the example of the viewing system for driving an Unmanned Ground Vehicle. The second approach was based upon developing advanced interface

designs. This approach is focussed on providing the operator with task critical cues (e.g. high quality visual motion cues for tracking tasks) that may not be inherently present in the tele–operating environment. Point of departure for this approach is that it does not increase the data–link requirements. Therefore, it employs new control devices (e.g. head–coupled control), and intelligence present in the control station (e.g. prediction techniques). Research has shown that both approaches can succeed in reducing the data–link and/or improving operator performance.

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